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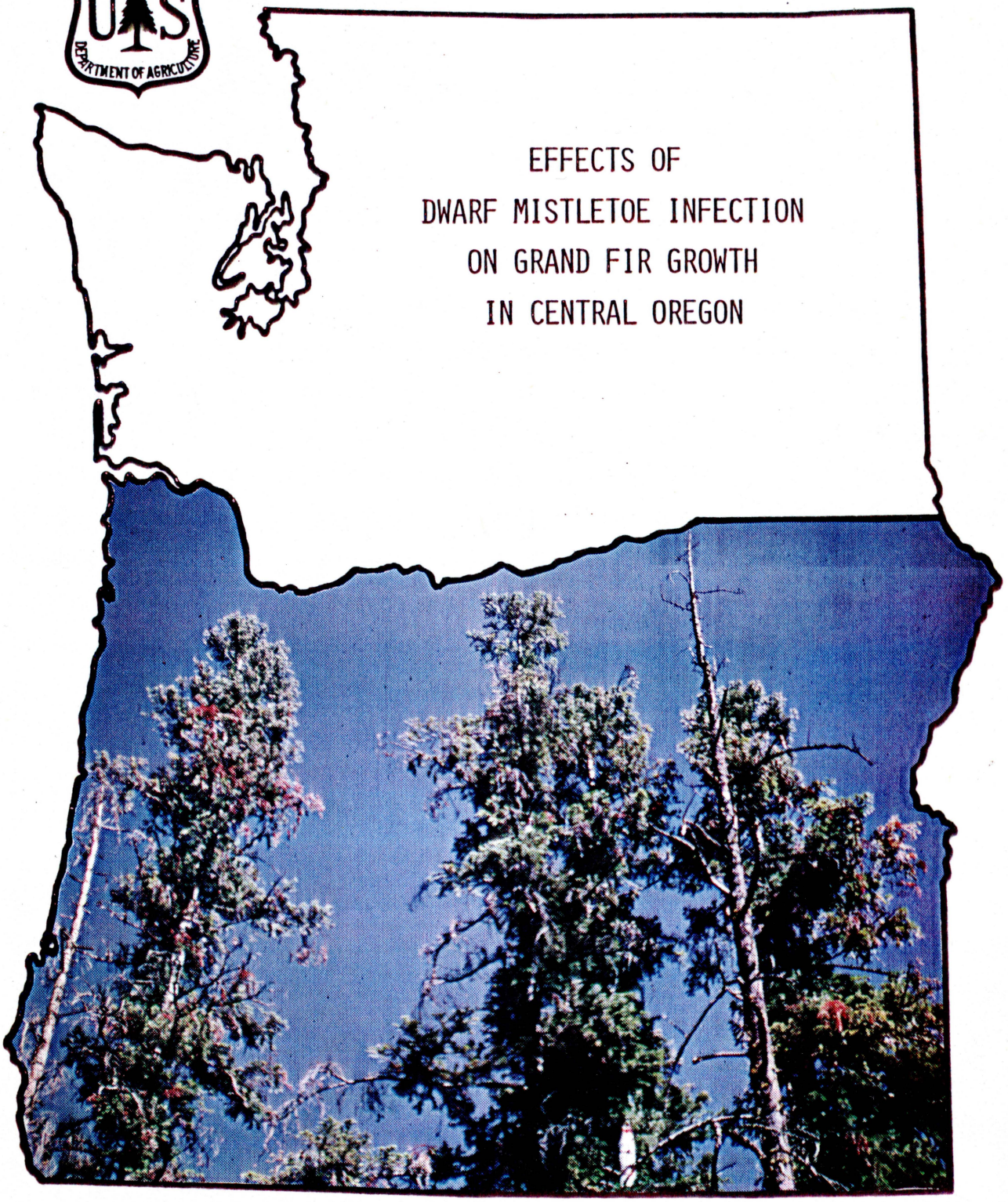

EFFECTS OF DWARF MISTLETOE INFECTION ON GRAND FIR GROWTH IN CENTRAL OREGON

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Effects of Dwarf Mistletoe Infection on Grand Fir Growth in Central Oregon

by

Gregory M. Filip
Pathologist

USDA Forest Service
State and Private Forestry
Forest Pest Management
Region 6
Portland, Oregon

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SUMMARY

1. Height and diameter growth data were collected from 57 dwarf mistletoe infected grand fir saplings and poles in stands thinned 5 years previous. Height and diameter growth rates were greatest in trees with high live crown ratios (LCR) and low dwarf mistletoe ratings (DMR), and least in trees with low LCR and high DMR.

2. Height and radial growth data were collected from 103 felled sawtimber size grand fir in three stands severely infected with dwarf mistletoe. Trees with high LCR and low DMR grew the fastest over the last 25 years, while trees with low LCR and high DMR grew the slowest; LCR was the more important factor.

3. Height and radial growth reduction by dwarf mistletoe was most dramatic in trees with high LCR and almost negligible in trees with low LCR.

4. In trees with high DMR, height growth reduction began over 25 years ago, whereas radial growth reduction began during the last 25 years.

5. LCR or DMR had no apparent effect on form class.

6. Within a given LCR class, the number of living branches decreased as DMR increased.

7. Of over 12,000 branches examined on 103 trees, more than one-third of the living branches, most of the dying branches, and nearly one-half of the dead branches were infected by dwarf mistletoe.

8. From a sample of 673 branches with dwarf mistletoe, it was determined that mean age when a branch became infected was 8 years and that it took an average of 11 years of parasitism for infections to kill a branch.

9. Oldest infections occurred in the lower crown in dead branches while youngest infections were found in the upper crown in live branches.

10. About 9 percent of the sampled branches also were infected by *Cytospora abietis*, cause of Cytospora canker.

11. A higher proportion of Cytospora cankers was found in dead and dying branches, in the lower crown, and in the older dwarf mistletoe infections than in living branches, upper crowns, or younger dwarf mistletoe infections.

12. Some of the sampled trees had root diseases, and one was successfully attacked by fir engravers. Other trees in the same stands with more serious dwarf mistletoe infections had a much higher incidence of either root diseases, fir engraver infestations, or both than trees with less severe dwarf mistletoe infection levels.

13. A model that explains the relationship between grand fir growth/mortality and attacks by dwarf mistletoe, Cytospora canker, fir engravers, and root diseases is presented.

14. Based primarily on the data we collected, management recommendations are presented for maintaining good growth rates and minimizing damage caused by dwarf mistletoe and associated pests in seedling, sapling, pole, and sawtimber size grand fir stands.

INTRODUCTION

White fir (*Abies concolor*) and grand fir (*A. grandis*) are major components of several cover types in Oregon and Washington. Because of an 85-year fire exclusion policy and past logging practices of leaving white and grand fir, the fire-intolerant true firs have encroached and/or replaced many former ponderosa pine (*Pinus ponderosa*) and lodgepole pine (*P. contorta*) stands in Oregon and Washington. Ease of reproduction, rapid growth when released, wide ecological amplitude, and the rising value of forest products now make white and grand fir highly desirable as timber species.

Several diseases including root rots, heart rots, and dwarf mistletoes can cause severe damage in stands of white or grand fir (Aho 1977; Filip and Aho 1977; Filip and Goheen 1982). Heart rots, primarily caused by *Echinodontium tinctorium*, and root diseases, chiefly caused by *Armillaria mellea, Fomes annosus,* and *Phellinus weirii*, occur throughout the entire range of white and grand fir in Oregon and Washington. Dwarf mistletoes, primarily white fir dwarf mistletoe (*Arceuthobium abietinum* f. sp. *concoloris*), are chiefly a problem on white and grand firs south of Yakima County in southern Washington, the northern limit of the pathogen (Hawksworth and Wiens 1972).

Dwarf mistletoes, including white fir dwarf mistletoe, infest about 21 percent of the true fir type in Oregon, Washington, and California (Bolsinger 1978). Biology of and damage caused by fir dwarf mistletoe and the often associated canker fungi on white firs and red firs (*A. magnifica*) in California are well documented (Wright 1942; Parmeter and Scharpf 1963; Scharpf 1964, 1969a, 1969b, 1977, 1979; Scharpf and Parmeter 1967, 1976; Scharpf and Bynum 1976). Filip and others (1978) have reported similar damage in Oregon noble fir (*A. procera*) and Pacific silver fir (*A. amabilis*), but information is lacking for grand fir in Oregon and Washington.

The biology of white fir dwarf mistletoe on grand fir in Oregon and Washington may be sufficiently different from that on white fir in California to cause more severe damage, a hypothesis developed by Scharpf on a recent visit to infected stands in central Oregon (see Functional Assistance Trip - Grand Fir Dwarf Mistletoe, Sept. 16, 1980). In fact, forest managers on the Deschutes National Forest have reported severe losses in partially released stands of mistletoe-infected grand firs and have requested that we reevaluate our guidelines for white fir dwarf mistletoe management, which were based solely on information from California. Deschutes National Forest managers are interested particularly in the fate of dwarf mistletoe-infected and partially released second-growth grand fir stands. Their main concerns are: (1) what is the effect of dwarf mistletoe on stand growth and mortality? and (2) can severely infected second-growth stands be maintained for at least 20 more years before appreciable stand deterioration occurs?

OBJECTIVES

Objectives of this evaluation were to:

(1) Determine the effects of dwarf mistletoe on growth of grand fir in the Deschutes National Forest,

(2) evaluate possible relationships among dwarf mistletoe, canker fungi, and affected branches, and

(3) formulate management recommendations for maintaining good growth rates and minimizing damage caused by dwarf mistletoe and associated pests.

I. Effects of dwarf mistletoe on tree growth

A. Sapling and pole-size stands

1. Methods

In August 1976, three permanent plots were established on the Bend Ranger District (Figs. 1 and 2). The plots contained grand fir saplings and poles (ave. DBH = 6.0 in., range = 1.9-12.2 in.) with varying intensities of infection by white fir dwarf mistletoe. The trees on each plot were thinned to approximately a 9 by 9 ft. spacing, and the best potential crop trees based on height and form were left. Residual trees were marked with numbered metal tags at breast height and measured for height, DBH, live-crown ratio (LCR), and dwarf mistletoe rating (DMR). Dwarf mistletoe was rated using the 6-class system of Hawksworth (1977).

In July 1981, trees on two of the three plots were remeasured for height, DBH, LCR, and DMR (the third plot could not be relocated). Heights were measured with a telescoping tree pole (Photo 1) for trees under 50 ft. tall and a clinometer for taller trees.

2. Results and Discussion

Fifty-seven trees were remeasured in 1981, and the data were pooled and arranged by DMR and LCR. Although the data were obtained after only 5 years, both height and diameter growth rates appeared greatest in trees with high LCR

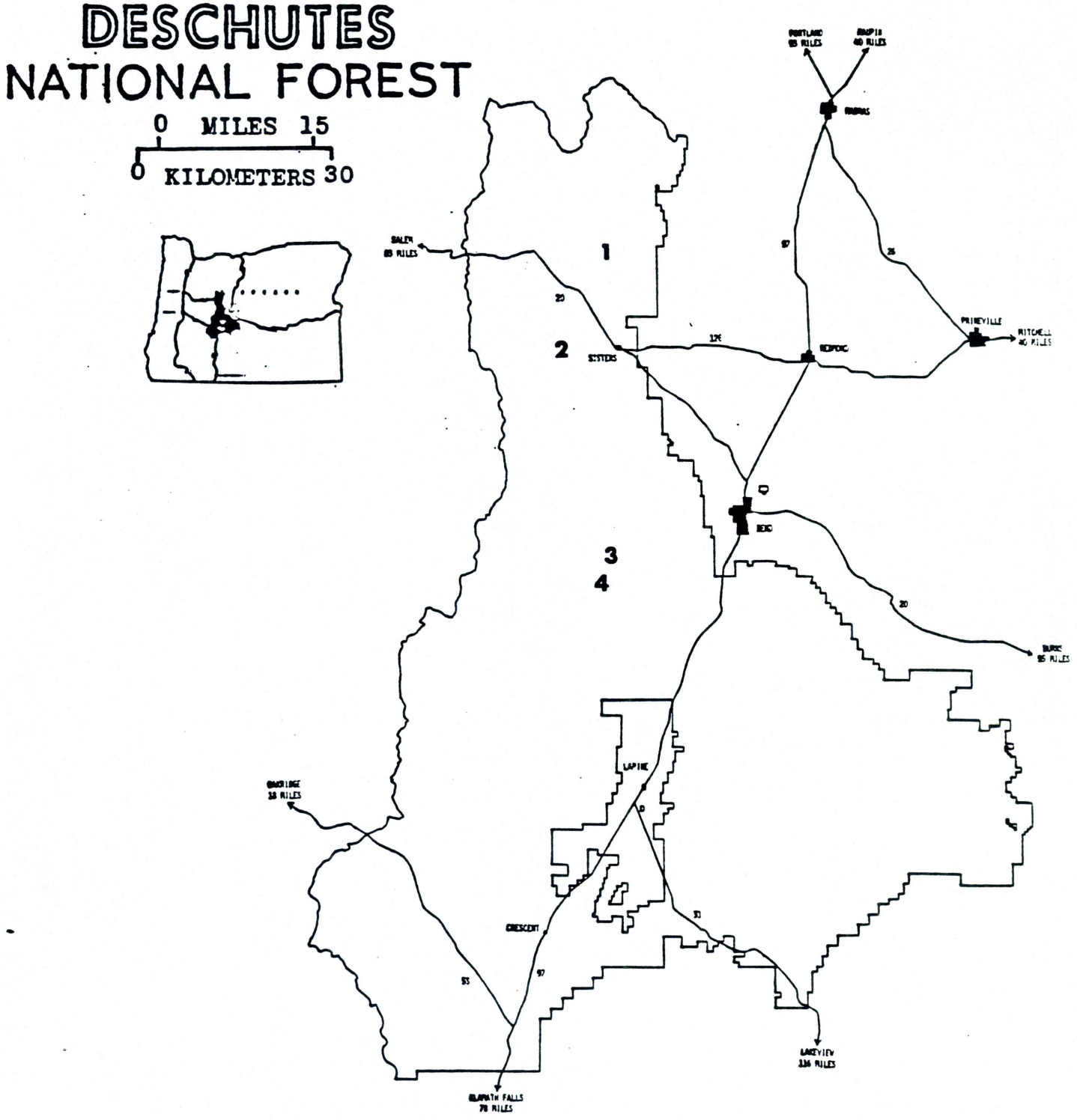


Fig. 1--Map showing approximate locations of two permanent plots (3 and 4) and three sawtimber plots (1, 2, and 3) on the Deschutes National Forest.

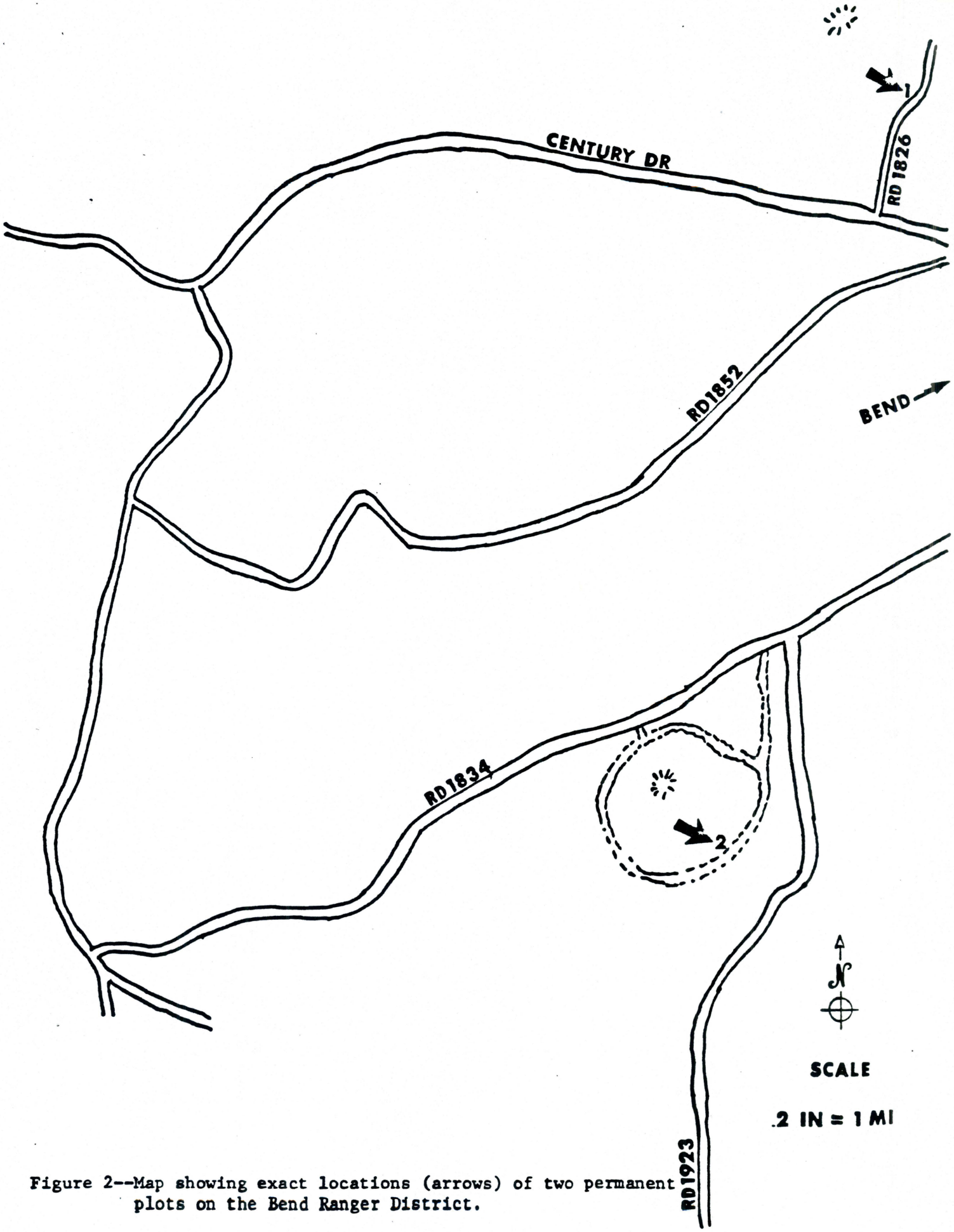


Figure 2--Map showing exact locations (arrows) of two permanent plots on the Bend Ranger District.

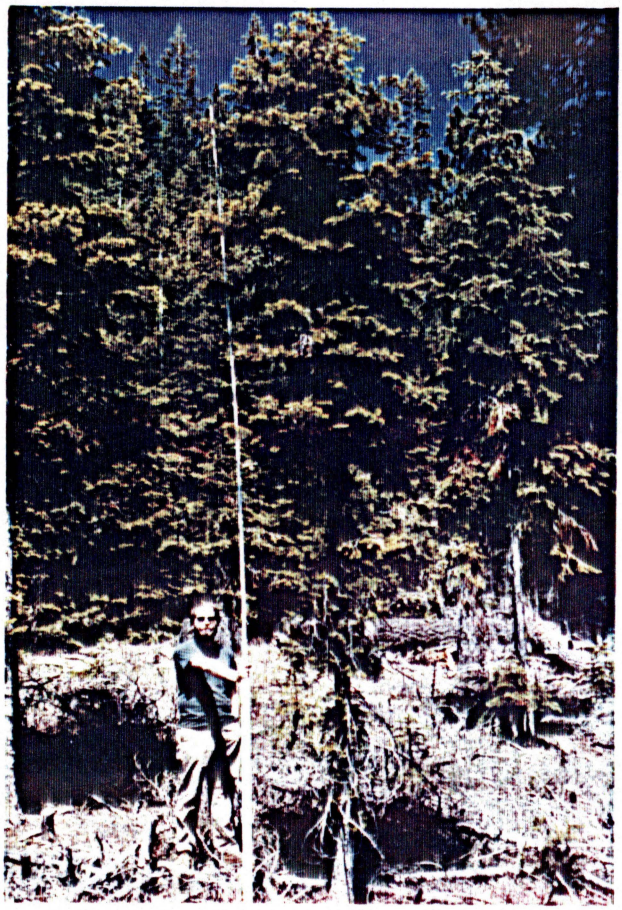


Photo 1--Precommercially thinned and dwarf mistletoe-infected stand of grand fir on the Bend Ranger District.

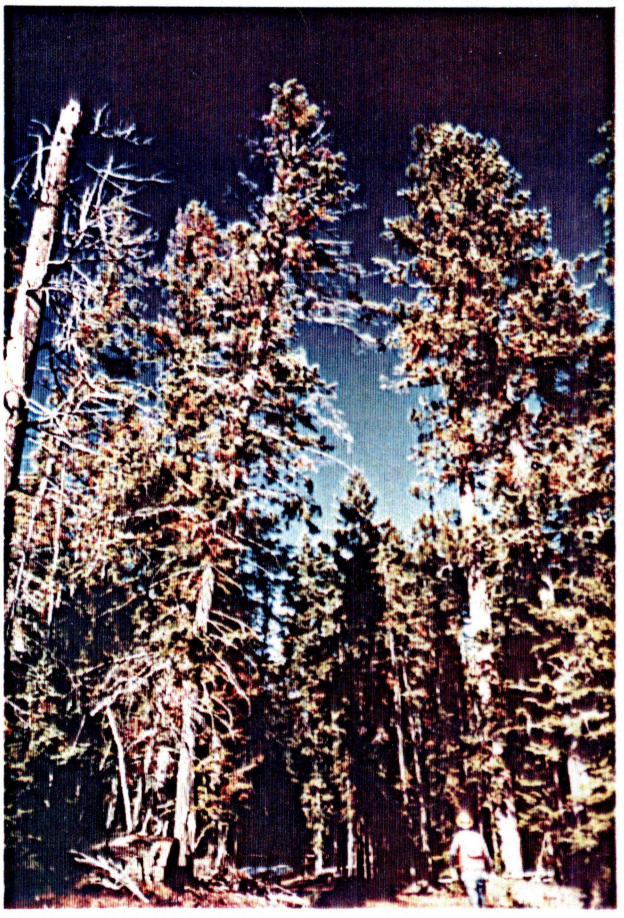


Photo 2--Dwarf mistletoe-infected grand fir stand typical of three examined for growth effects.

and low DMR and least in trees with low LCR or high DMR (Table 1). Seidel (1977, 1980) found similar responses for red and grand firs in Oregon and Scharpf (1979) for red fir in California.

Table 1--Height and diameter (BH) growth of sapling and pole grand fir 5 years after thinning, by live crown ratio and dwarf mistletoe rating, Deschutes National Forest, Oregon.

Live Crown Ratio (LCR) %		Dwarf Mistletoe Rating (DMR) Low 0, 1, 2	Medium 3, 4	High 5, 6	Ave.
		5-Year Growth			
80-100	ft.	3.5	2.9	1.4	2.8
	in.	2.1	1.5	1.0	1.6
	n	4	8	3	15
60-79	ft.	1.6	2.0	0.6	1.7
	in.	1.4	1.6	0.9	1.5
	n	14	13	2	29
40-59	ft.	1.1	2.4	0.5	1.1
	in.	1.2	1.8	0.9	1.2
	n	7	2	4	13
Ave.	ft.	1.8	2.3	0.8	1.9
	in.	1.5	1.6	0.9	1.4
	n	25	23	9	57

After overstory removal, Gordon (1973) reported a 4-year lag in height growth of white fir and red fir in California. Several of the uninfected trees that we measured also had little or no height growth after 5 years. We hope that future measurements will better determine the effects of LCR and DMR on growth when this lag period has passed.

B. Sawtimber Stands

1. Methods

In November 1980 and July-September 1981, sample trees were selected in two stands on the Sisters Ranger District and one on the Bend Ranger District (Fig. 1). Each stand was severely infected with white fir dwarf mistletoe and contained second-growth grand fir beneath an overstory of mixed old-growth ponderosa pine and grand fir that had been partially removed during several entries (Photo 2). From each stand, at least 36 second-growth grand firs were selected to fill four categories of LCR (20-39%, 40-59%, 60-79%, and 80-100%) and three classes of DMR (high = 5, 6; medium = 3, 4; and low = 0, 1, 2) with three replications of each. Site index at base 100 years was determined for each stand using height and age of three dominant or codominant sample trees per stand with LCR $\geq$80% and DMR $<$3.

Selected trees were as similar as possible with respect to size and amount of surrounding competition. Also, sample trees were free of conks, top-damage, and severe trunk wounds not associated with dwarf mistletoe infections.

Data collected before felling each tree included (1) LCR, estimated using a clinometer, (2) DMR, estimated with binoculars, and (3) basal area of all nearest neighboring trees established using a wedge prism (20 or 40 BAF).

After felling, trees were measured for (1) total height, (2) height to base of live crown (height to lowest living branch at the bole excluding adventitious branches), (3) height growth at 5-year intervals for the last 25 years based on internode length (five-year intervals were determined by counting internodes or by sectioning leaders and counting annual rings), (4) number of all primary branches with and without dwarf mistletoe infection stratified by branch condition (living, dying, or dead) and crown position (top, middle, or bottom), and (5) number of dwarf mistletoe stem infections.

One-inch thick disks were removed at the stump (1.0 ft.), breast height (4.5 ft.), top of the first 16-foot log, and at the 4 in. diameter top. Data recorded for each disk, except at the stump, included (1) diameter inside bark (d.i.b.), (2) total age, and (3) radial growth at 5-year intervals for the last 25 years across three randomly chosen radii. Only total age, d.i.b., and year(s) of release were recorded for stump disks. Past (25 years ago) and current total merchantable volumes ($ft.^3$) were calculated to a 4-in. diameter top for each tree using the R6 FIDM* STAT CUBS Program (Lampi, personal communication). Form class (Girard) was calculated by dividing d.i.b. at the top of the first 16-foot log by DBH.

A three-way analysis of variance for a randomized complete block design (4 x 3 x 3 factorial) was used to determine independent effects and interactions of LCR, DMR, and stand location on radial, height, and volume growth (Nie and others 1975).

2. Results and Discussion

One hundred and three trees averaging 115 years old and 15 in. DBH were sampled in three stands (Table 2). Years since release of the sample trees varied greatly due to the selective harvesting and mortality pattern of the overstory during several decades. To obtain a representative sample of all live crown ratios, it was necessary to select trees subjected to varying degrees of competition, since LCR is affected by the amount of competition. Basal area ($ft.^2$) of trees surrounding each sample tree was used to estimate the amount of competition, which ranged from 0 to 680 $ft.^2$. Trees with zero $ft.^2$, or essentially free-growing trees, had the highest LCR, whereas the higher basal area values or trees with severe competition usually had the lowest LCR. Free-growing trees with low LCR could not be found.

Table 2—Characteristics of sample trees from three grand fir stands on the Deschutes National Forest, Oregon.

Stand No	Site Index Age 100	No. Sample Trees	Total Age (Yr.) Mean	Total Age (Yr.) Range	DBH (In.) Mean	DBH (In.) Range	Years Since Release Mean	Years Since Release Range	Basal Area ($ft.^2$) Around Sample Trees Mean	Basal Area ($ft.^2$) Around Sample Trees Range
1	80	28	102	70-150	15.5	11.0-20.5	50	16-97	170	40-440
2	62	38	124	74-173	15.2	11.4-19.6	78	11-121	181	0-360
3	68	37	130	74-197	15.1	10.9-21.6	79	45-109	248	0-680
Total or Ave.	—	103	115	70-197	15.2	10.9-21.6	72	11-121	202	0-680

Trees with the highest LCR (usually dominants) and lowest DMR (Photo 3) grew the fastest over the past 25 years, while trees with the lowest LCR (usually intermediates) and highest DMR grew the slowest (Figs. 3, 4, and 5). These results are similar to those found by Scharpf (1979) in red fir in California. We found that the relationships between LCR-DMR and radial, height, and volume growth were all significant to at most the 1.5% level. LCR explained 27-49% of the variation in growth, and DMR 22-24%. Seidel (1980) also found that LCR was the single best variable explaining height and diameter growth of grand fir in Oregon, accounting for 30 percent of the variation. Scharpf (1979) found similar results concerning red fir in California.

Because no significant differences were found among the three stands, the data were pooled. Also, since radial growth data at the top of the first 16-foot log and at the 4 in. diameter top were similar to growth rates at breast height, these data are not presented.

The effect of dwarf mistletoe on growth rates appeared greatest in trees with LCR >80%, the fastest growing trees, and became almost negligible in trees with LCR <40%, the slowest growers. The interaction between LCR and DMR was significant ($P = .05$) for height growth but not for radial or volume growth. Also, trees with DMR = 0, 1, or 2 grew at a faster rate than trees with DMR = 3 or 4. At DMR = 5 or 6, growth rate was considerably slower than that of moderately infected trees, especially those with high LCR. For instance, at LCR = 80-100%, growth rates over the past 25 years of trees with high DMR were almost half those of trees with low DMR (Photo 4)!

Growth rates of healthy trees that we measured were lower than growth rates recorded by Scharpf (1979) for healthy trees with the same LCR. Scharpf studied fully released and essentially open-grown red fir with a high site index. We studied partially released grand fir where competition within the understory was often severe and site quality was low.

Growth reduction by dwarf mistletoe, especially at high LCR, was much more dramatic in our evaluation than in Scharpf's. This may be due to differences in the following: site quality, previous stand management, tree species, and dwarf mistletoe variety (a different variety of *A. abietinum* infects red fir). Since it was not possible for us to locate fully released stands on sites similar to those used by Scharpf, we cannot attribute the difference in our results to differences in tree species or mistletoe variety alone.

Photo 3--Grand firs with the highest live crown ratios and lowest dwarf mistletoe ratings grew the fastest over the past 25 years.

Photo 4--Five-year radial growth periods (indicated by dots) on discs from grand fir with high dwarf mistletoe rating (upper) and low dwarf mistletoe rating. Both trees had 80-100% live crown ratios.

Fig. 3 - Periodic annual merchantable volume increment (last 25 years) of grand fir infected with dwarf mistletoe, Deschutes National Forest, Oregon.

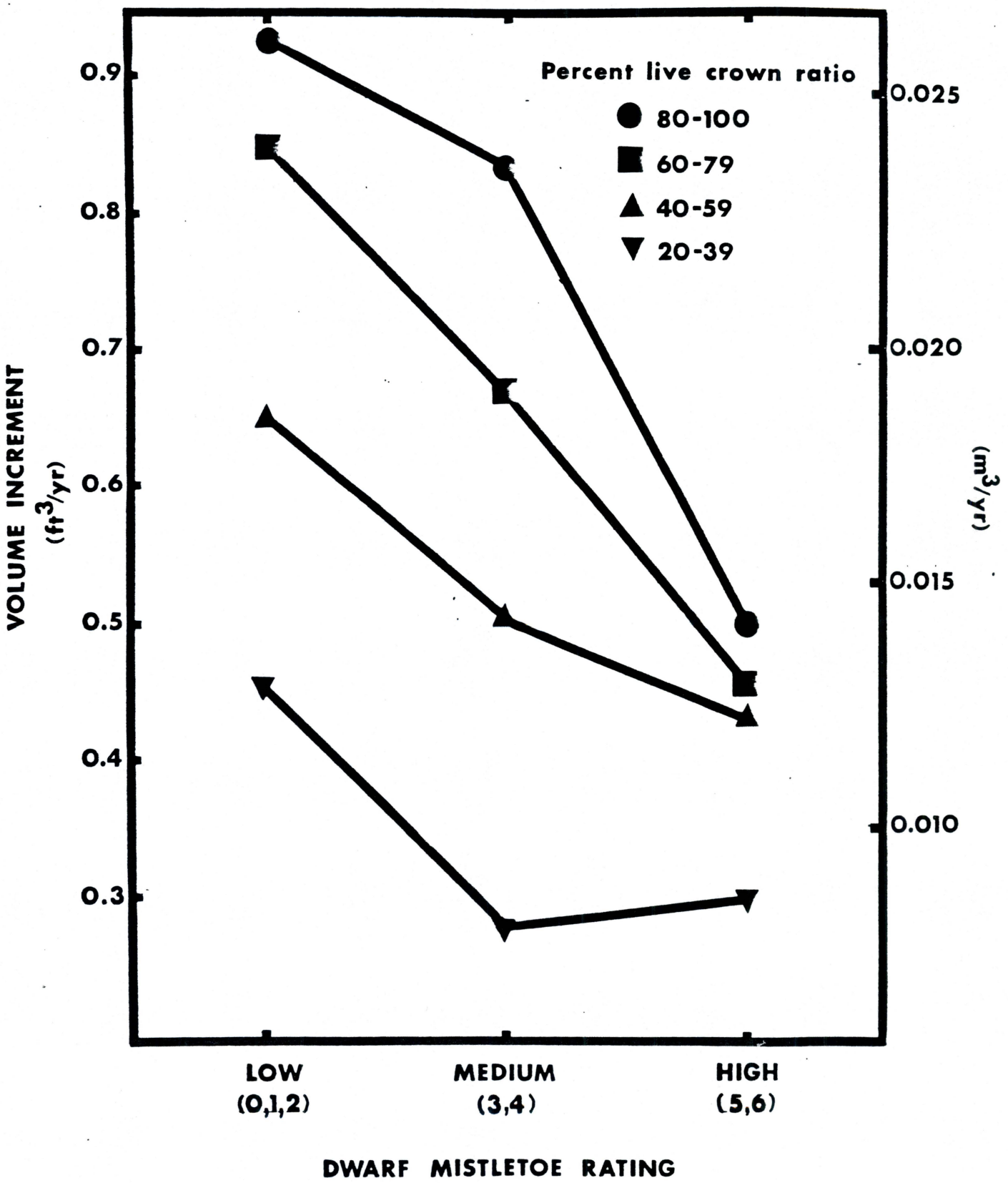


Fig. 4 - Periodic annual radial (at 4.5 ft.) increment (last 25 years) of grand fir infected with dwarf misteltoe, Deschutes National Forest, Oregon.

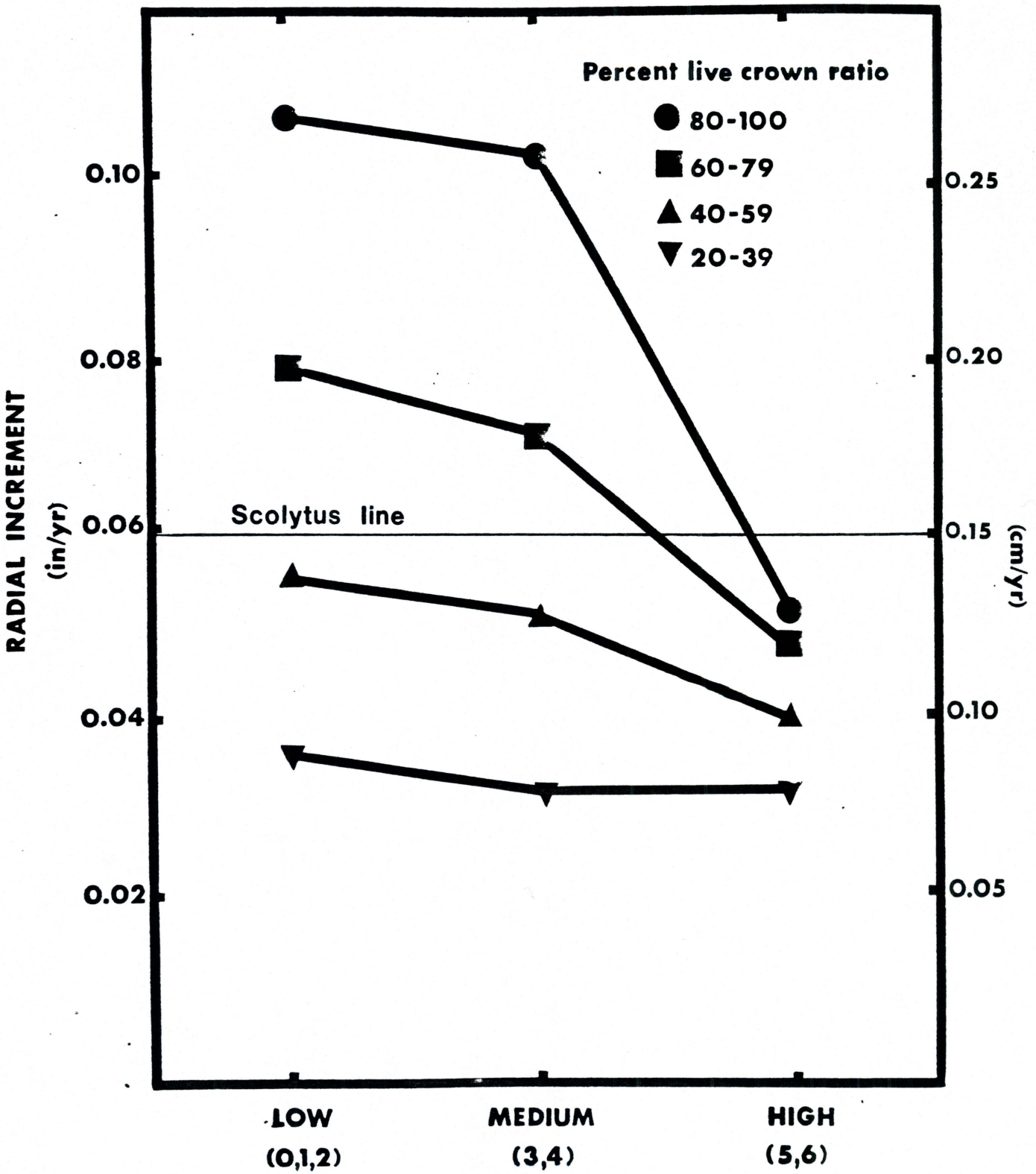
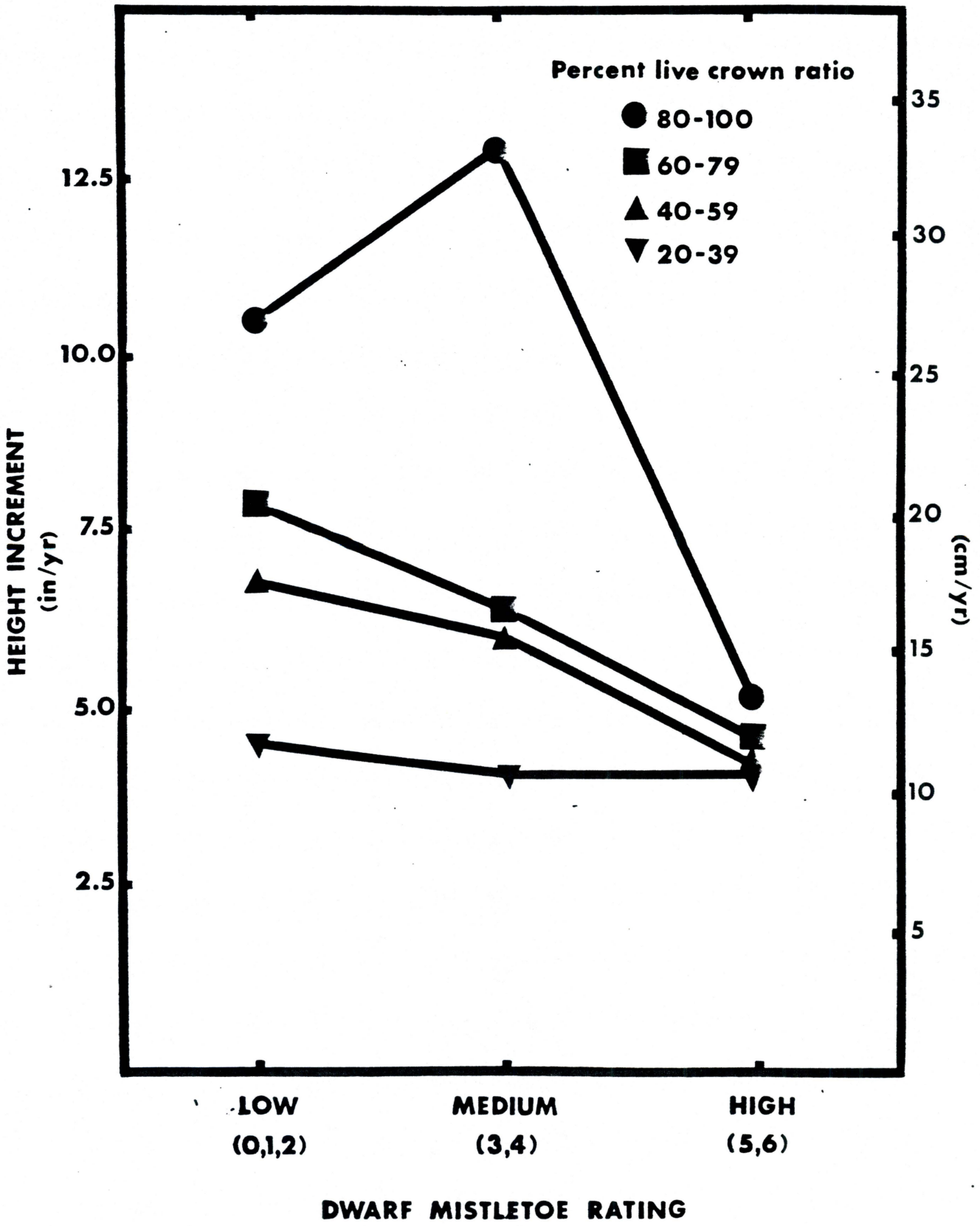


Fig. 5 - Periodic annual height increment (last 25 years) of grand fir infected with dwarf mistletoe, Deschutes National Forest, Oregon



Periodic annual increment for height and radial growth was similar for all of our sample trees prior to the last 25 years (Figs. 6 and 7). Height and radial growth rates for trees with low and mid DMR increased slightly for 1956-61 over the previous period. For trees with high DMR, radial growth rate increased slightly but height growth rate decreased for 1956-61 in comparison to the previous period. This indicates that dwarf mistletoe decreases height growth rate before radial growth rate. Also, the debilitating effects of dwarf mistletoe on height growth in trees with current high DMR began over 25 years ago; the effect on radial growth began during the last 25 years.

Comparison of form classes by LCR and DMR shows no apparent differences (Fig. 8). This is similar to what Scharpf (1977) found for red fir in California. Radial growth reductions by dwarf mistletoe are relatively uniform over the entire stem in grand fir.

Scharpf (1979) found that heavy dwarf mistletoe infections reduced LCR in red fir by 10 percent. Although we did not measure the reduction of LCR by dwarf mistletoe, we found that in grand fir, dwarf mistletoe did appear to reduce LCR by killing branches in the lower crown. More importantly, however, dwarf mistletoe kills branches within the crown. We found that within a given LCR class, the number of living branches per feet of total tree height (live branch ratio) decreased by 20-45% as DMR increased (Fig. 8).

Of over 12,000 branches examined on 103 trees, 55 percent were living without dwarf mistletoe, 33 percent were living with dwarf mistletoe, and the remainder were either dead or dying (Table 3). Almost half of the dead branches were killed by dwarf mistletoe. The cause of death of the remaining branches could not be positively identified, but most were in the lower crown and probably were shade-killed. A few may have been killed by canker fungi alone. Most of the dying branches were infected with dwarf mistletoe.

Table 3--Number of branches from 103 trees by presence or absence of dwarf mistletoe infections and branch condition in three stands, Deschutes National Forest, Oregon.

	Branch Condition						
	With Mistletoe			Without Mistletoe			
	Live	Dying	Dead	Live	Dying	Dead	Total
	No. of Branches						
Stand 1	1146	321	246	2075	29	226	4043
Stand 2	1494	237	152	2523	6	98	4510
Stand 3	1433	31	16	2200	0	122	3802
Total	4073	589	414	6798	35	446	12355
Percent	33	5	3	55	1	4	100

We found few bole infections by dwarf mistletoe on sample trees, however, those found usually were in the more severely infected trees (DMR = 5 or 6). This agrees with reports by Scharpf (1969a) for red fir. Trunk swellings may

Fig. 6 - Periodic annual height increment of grand fir infected with dwarf mistletoe, Deschutes National Forest, Oregon

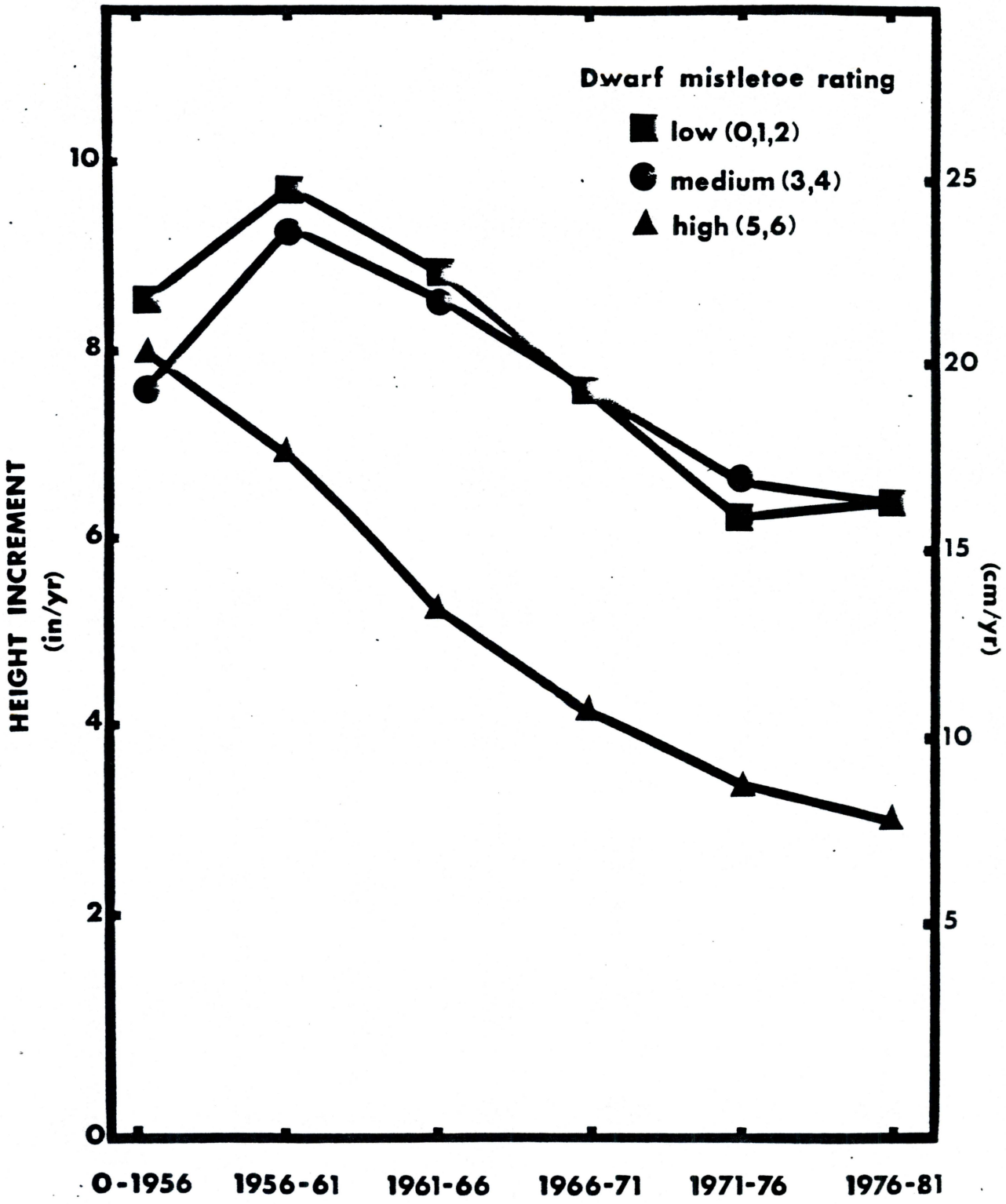


Fig 7. - Periodic annual radial (at 4.5 ft.) increment of grand fir infected with dwarf mistletoe, Deschutes National Forest, Oregon

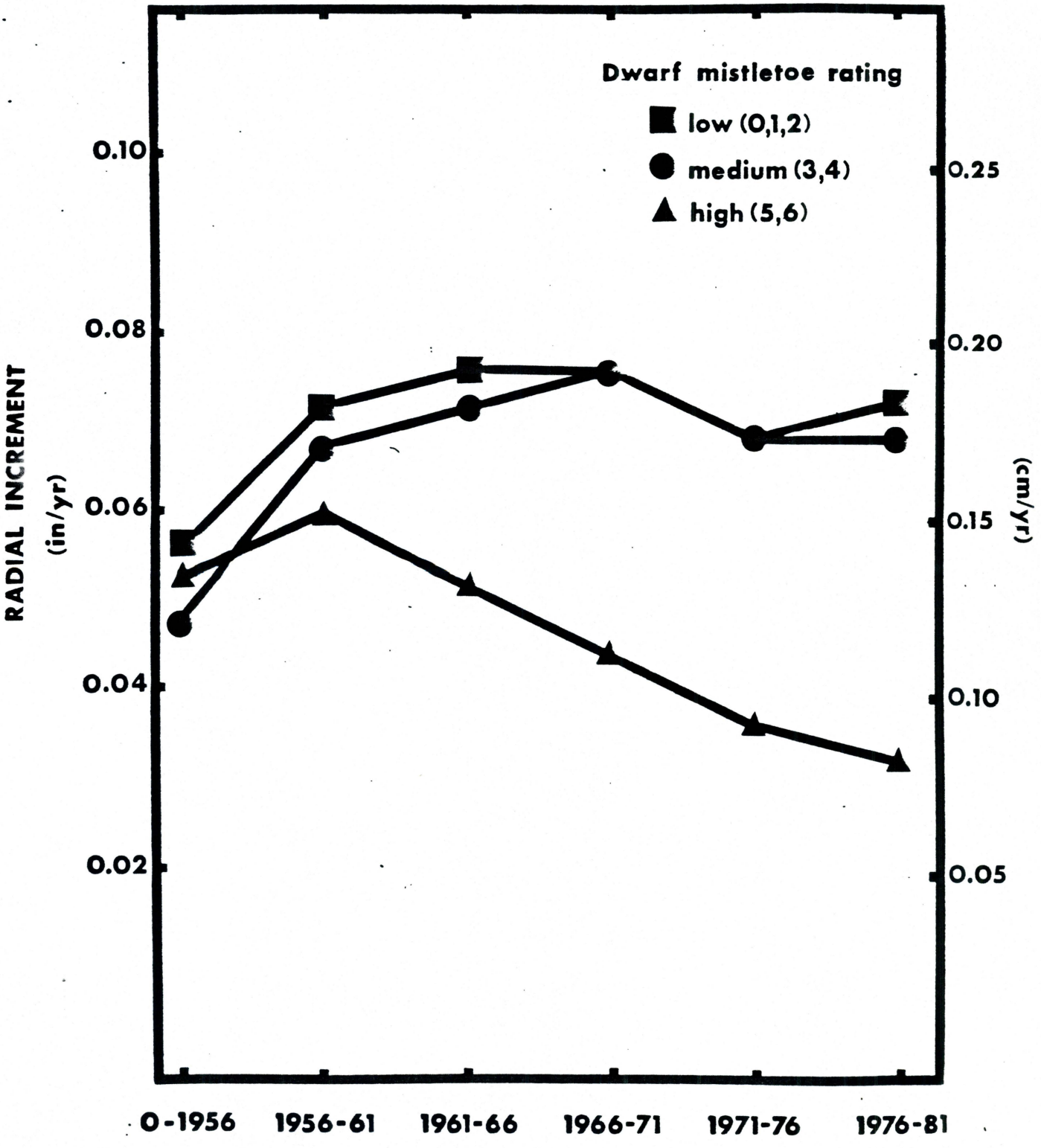


Fig. 8

Summary of growth data for sampled grand firs by live crown ratio (LCR) and dwarf mistletoe rating (DMR).
RAD=Radial growth; HT=Height growth; VOL.=Volume growth; LBR=Live branch ratio; N=No. of samples; CP=Cutting priority; FC=Form class.

LCR	DMR 0,1,2	DMR 3,4	DMR 5,6
80-100 %	RAD.=0.11 in./yr. HT.=10.6 in./yr. VOL.=0.92 ft.^{3}/yr. LBR=2.44 FC=71 CP=4 N=9	0.10 13.0 0.83 2.02 71 4 8	0.05 5.2 0.50 1.35 71 2 9
60-79 %	0.08 8.0 0.85 1.71 75 3 8	0.07 6.5 0.67 1.86 73 3 12	0.05 4.6 0.46 1.28 74 2 10
40-59 %	0.06 6.8 0.65 1.31 74 2 11	0.05 6.3 0.51 1.38 74 2 9	0.04 4.3 0.43 1.11 73 1 11
20-39 %	0.04 4.6 0.45 1.12 80 1 6	0.03 4.2 0.28 0.97 69 1 4	0.03 4.2 0.30 0.90 75 1 6

have little effect on wood quality and growth of released firs, and cull and breakage may be minimal over projected rotations of second-growth stands (Scharpf 1979). However, in old-growth grand fir stands, bole infections may render logs unmerchantable if the swellings break open and decay. Also, in developed recreation sites where old-growth stands often predominate, trees may break at open bole infections and thus pose serious hazards to recreationists and property.

II. Relationships among dwarf mistletoe, canker fungi, and affected branches

1. Methods

A total of nine 6-inch long branch sections, three from dead branches (no needles), three from dying branches (red needles), and three from living branches, all with dwarf mistletoe infections, were collected throughout the crown of each felled tree in the three stands (Photos 5 and 6).

In the lab, each branch section was dissected to determine branch age (at that point) and age of dwarf mistletoe infection according to Scharpf and Parmeter (1966). Sections were then cleaned of loose debris and dwarf mistletoe aerial shoots. Outer bark covering swellings was removed and five wood chips from the inner bark or cambium of each were aseptically removed with a wood gouge. Chips were plated on 2 percent water agar and incubated for 1 week at room temperatures. Fungi that grew on the plates were hyphal tipped and transferred to potato dextrose agar to culture suspected isolates of canker fungi (Scharpf 1969b, Filip and others 1978). Only dwarf mistletoe-infected branches were sampled for canker fungi since Scharpf found only 4 percent of nonmistletoe-infected branches with Cytospora canker, and Filip and others (1978) found no nonmistletoe-infected branches with canker fungi in noble and Pacific silver fir.

2. Results and Discussion

Data from the sample of 674 dwarf mistletoe-infected branches are presented in Table 4. The average branch age when it became infected was 8 years, with a range of 1 to 37 years. Also, it took an average of about 11 years of parasitism (range 3-48 years) for dwarf mistletoe infections to kill a branch.

Table 4—Data from sampled dwarf mistletoe-infected branches from 103 grand firs in three stands, Deschutes National Forest, Oregon.

	Stand 1			Stand 2			Stand 3			All Stands		
	n	$\bar{x}$	range	n	$\bar{x}$	range	n	$\bar{x}$	range	n	$\bar{x}$	range
Branch Age (Yrs.)	194	16.2	2-61	239	17.6	3-56	241	15.2	4-49	674	16.4	2-61
Age Branch Infected (Yrs.)	194	7.2	1-35	238	9.3	1-31	241	7.4	1-37	673	8.0	1-37
Years dwarf mistletoe took to kill branch												
with *Cytospora*	20	10.5	3-18	13	15.8	4-48	8	12.0	6-26	41	12.5	3-48
without *Cytospora*	70	10.4	3-28	40	12.0	3-31	13	10.5	7-26	123	10.9	3-31
All	90	10.5	3-28	53	12.9	3-48	21	11.0	6-26	164	11.3	3-48

Photo 5--Sampling sawtimber-size grand fir in one of three stands on the Deschutes National Forest.

Photo 6--Dwarf mistletoe-infected branch section with outer bark removed. *Cytospora abietis* was often isolated from between living (green) and dying (brown) tissue.

Age of 673 dwarf mistletoe infections is presented in Table 5. Oldest infections (the oldest = 48 years) were found in the lower crown in dead branches, probably because the oldest branches in the lower crown were targets for mistletoe seeds for the longest time. Infections probably occurred earlier than 48 years ago, but infected branches may have subsequently died and disintegrated. Conversely, the youngest infections were found in the upper crown in living branches.

Table 5--Age of dwarf mistletoe infections from 673 sampled branches of 103 grand firs by crown position and branch condition in three stands, Deschutes National Forest, Oregon.

			Dwarf Mistletoe Age (Yrs.)			
			Stand 1	Stand 2	Stand 3	All Stands
CROWN POSITION	Top	n	57	69	60	186
		x	6.5	6.2	7.1	6.6
		range	2-13	1-16	2-17	1-17
	Mid	n	72	86	89	247
		x	8.7	7.7	7.5	7.9
		range	3-28	2-21	1-18	1-28
	Bottom	n	65	83	92	240
		x	10.6	10.8	8.6	9.9
		range	3-29	3-48	1-26	1-48
	Total	n	194	238	241	673
		x	8.7	8.4	7.8	8.3
		range	2-29	1-48	1-26	1-48
BRANCH CONDITION	Living	n	104	181	220	505
		x	7.5	6.9	7.5	7.3
		range	2-29	1-23	1-25	1-29
	Dying	n	45	31	13	89
		x	9.2	11.9	10.1	10.3
		range	3-26	3-27	6-14	3-27
	Dead	n	45	26	8	79
		x	11.3	14.2	12.6	12.4
		range	3-28	5-48	7-26	3-48
	Total	n	194	238	241	673
		x	8.7	8.4	7.8	8.3
		range	2-29	1-48	1-26	1-48

Information about Cytospora canker is shown in Table 6. About 9 percent of the sampled branches had Cytospora canker. Scharpf (1969b) found 20 percent in white fir in California. Our 9 percent figure compares favorably with the 7 percent incidence that we obtained by sampling noble and Pacific silver fir on the adjacent Willamette National Forest (Filip and others 1978). However, unlike the case with noble and Pacific silver fir, we did not find a significant number of canker fungi other than *C. abietis* in grand fir.

Table 6--Data concerning dwarf mistletoe-infected grand fir branches with and without *Cytospora abietis* by branch condition, crown position, branch age, and dwarf mistletoe age from 103 trees in three stands, Deschutes National Forest, Oregon.

	Branch Condition				Crown Position			Branch Age		DM Age	
	Total	Living	Dying	Dead	Top	Middle	Bottom	x	range	x	range
	No. of Branches							Yrs.		Yrs.	
Stand 1 (East Slope)											
With *Cytospora*	24	4	12	8	5	9	10	19.3	11-44	10.2	6-17
Without *Cytospora*	170	100	33	37	52	63	55	15.8	2-61	6.8	1-35
Stand 2 (Bend)											
With *Cytospora*	16	3	7	6	3	4	9	24.0	10-56	14.6	4-48
Without *Cytospora*	186	146	20	20	53	68	65	17.8	3-45	8.2	1-31
Stand 3 (Wiskey Springs)											
With *Cytospora*	16	8	4	4	2	1	13	21.1	8-38	10.9	4-26
Without *Cytospora*	225	212	9	4	58	88	79	14.8	4-49	7.6	1-18
All Stands											
With *Cytospora*	56	15	23	18	10	14	32	21.2	8-56	11.7	4-48
Without *Cytospora*	581	458	62	61	163	219	199	16.0	2-61	7.6	1-35

We found a higher proportion of Cytospora canker in dead and dying branches than in living branches. This differed from what we found in noble and Pacific silver fir and what Scharpf (1969b) found in white fir where Cytospora canker was equally common in living, dying, and dead branches. Also, we found a higher proportion of Cytospora canker in the lower crown in older dwarf mistletoe infections than in upper crown younger infections.

A higher proportion of Cytospora canker occurred in the older dwarf mistletoe age classes. Canker presence by dwarf mistletoe age class is as follows: 0-5 years, 2 percent of branches; 6-10 years, 8 percent of branches, 11-15 years, 15 percent of branches; 16-20 years, 21 percent of branches; and 21+ years, 21 percent of branches. This differs from what Scharpf (1969b) found where Cytospora canker occurred equally throughout all dwarf mistletoe age classes.

The association of Cytospora canker with the older dwarf mistletoe infections in dying or dead branches supports its role as a weak parasite attacking branches weakened by other causes (Wright 1942, Scharpf 1969b). As suggested by Scharpf (1969b), dwarf mistletoe-infected branches with bark cracks and basal cups, common in older infections, may provide suitable infection courts for *C. abietis*. Also, the swollen branch tissue and endophytic system of dwarf mistletoe are high in carbohydrates and may be highly favorable for *C. abietis* growth (Scharpf 1969b). However, both Wright (1942) and Scharpf (1980) found severe branch girdling in *C. abietis*-inoculated and nonmistletoe-infected but wounded white and noble fir branches and seedlings. It is possible that once the fungus becomes established in primarily older dwarf mistletoe infections, it hastens mortality of that branch. This would not be evident if comparisons are made between branches with and without *C. abietis* regarding years dwarf mistletoe took to kill a branch (Table 9) since *C. abietis* infects older dwarf mistletoe infections.

III. Presence of Secondary Pests

1. Methods

Secondary pests besides *Cytospora* were recorded for each of the 103 sample trees. Patches of bark killed by fir engravers (*Scolytus ventralis*) were noted on felled trees. Presence of heart rots, especially Indian paint fungus (*E. tinctorium*), was recorded as trees were sectioned. Root diseases were identified by examining major roots at the root collar if stain and/or decay were present at the cut stump. Also, stump disks collected from each tree were soaked in a 25 percent chlorox solution, rinsed with water, placed in plastic bags with wet newspaper, and incubated at ambient temperature for 14 days to reveal infection by *Fomes annosus*, a common root and butt-rotting fungus of true firs.

2. Results and Discussion

Although we selected several trees with high DMR in all four LCR classes, none of those trees had reached the stage where only adventitious branches constituted the living crown. These trees were severely infected by dwarf mistletoe and root diseases, and infestations of fir engravers were often detected. We observed several such trees in the stands sampled (cover photo).

Fir engravers attack trees weakened by other factors. Felix and others (1971) and Ferrell (1974) have shown that severe true mistletoe (*Phoradendron bolleanum* subspecies *pauciflorum*) infections render white firs more susceptible to fir engraver attacks. Although similar results have not been shown for dwarf mistletoe, it has been demonstrated that the weakening effect of dwarf mistletoe is much more severe than that of true mistletoe. Lane and Goheen (1979) reported that 80 percent of the grand fir in Oregon and Washington with recent *S. ventralis* attacks had advanced cases of root disease.

Recently, Robert Dolph, Region 6 Forest Pest Management Entomologist, constructed a graph relating radial tree growth to attack by fir engravers. If his findings hold true in our case, then a tree of DBH 15 inches, the mean of our sample trees, becomes highly susceptible to fir engraver attack after radial growth falls below 0.06 in. A line drawn at 0.06 in. on Fig. 4 shows that all of our sample trees with high DMR, regardless of LCR, were highly susceptible to insect attack. Also, all trees below 60 percent LCR regardless of DMR, were highly susceptible to fir engraver attack. Although only one of our sample trees had been successfully attacked by fir engravers--it also had a DMR of 5, radial growth (at BH) of 0.08 in., and was infected by *A. mellea* and *F. annosus*--several other trees in the stand with more severe dwarf mistletoe infections had been successfully attacked by fir engravers.

Ferrell (1980) tackled the problem of predicting tree mortality for mature red and white fir in California. By rating such characteristics as branch angle percent, crown density, crown raggedness, and presence or absence of bark fissures, he was able to predict the probability of white fir mortality within 5 years. Using his system and rating these same characteristics, we predict that 5-10 percent of our sample trees with DMR 5 or 6 would have died within 5 years from when we sampled. Obviously, the percentage would be much higher over a 20-year period.

We tested 103 trees for presence of *Fomes annosus*. Twenty-three trees (22%) were positive, and fourteen of these infected trees were in one stand (East Slope). Four of these trees also had root rot caused by *A. mellea*. In comparing the 14 trees in the one stand, no apparent correlation was found between presence or absence of root disease and LCR, DMR, or periodic annual volume growth for the last 25 years. Possibly because root disease was in an early stage on most of the 14 sample trees--only one tree had butt rot, four had stain, and the remaining nine had no apparent stain or decay although they were infected by *F. annosus*--it had not yet affected tree growth.

Although we tried to avoid selecting trees with broken tops or major trunk wounds not associated with mistletoe, we found after felling that 28 of 103 trees had at least one trunk wound--although most were minor--and four trees had broken tops. After bucking each tree, we found that two trees in one stand had advanced decay caused by *E. tinctorium*, and one of these trees had a trunk wound. Heart rot caused by *E. tinctorium* accounts for most of the decay found in white and grand fir stands in Oregon and Washington and is often associated with wounds (Aho 1977). Although it has not been studied, dwarf mistletoe infections in true fir may (1) increase susceptibility to infection by *E. tinctorium* by suppressing growth of advance regeneration, and (2) promote heart rot caused by *E. tinctorium* through wounds caused by bole infections.

IV. Grand Fir Growth-Infection-Mortality Model

The processes of tree growth, dwarf mistletoe infection, and subsequent attack by secondary pests are dynamic events that occur during grand fir stand development and decline. The following model is proposed (Fig. 9).

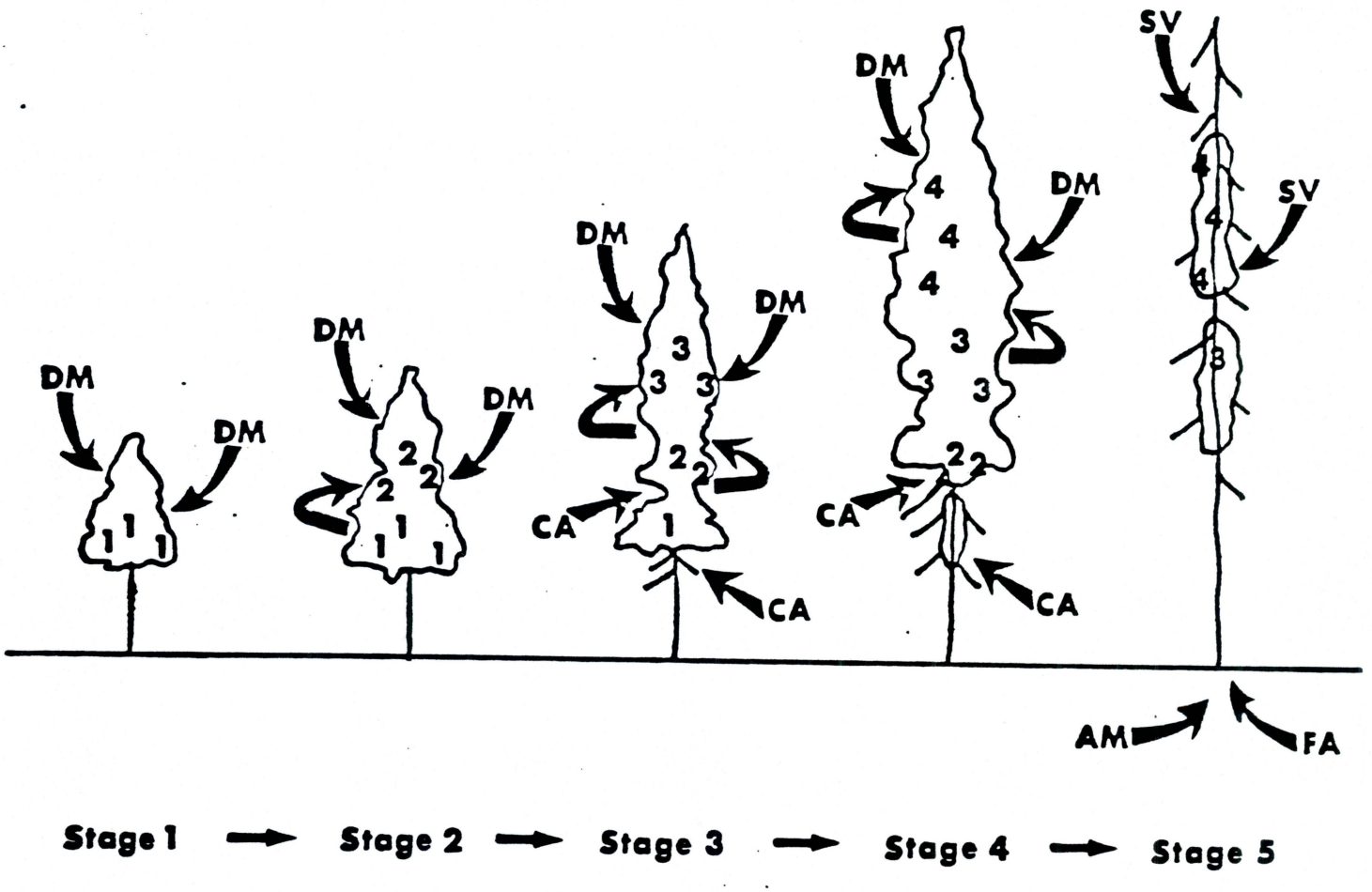


Fig.9 Proposed grand fir growth-infection-mortality model.
DM = Dwarf mistletoe, CA = *Cytospora abietis*, SV = *Scolytus ventralis*,
AM = *Armillaria mellea*, FA = *Fomes annosus*, 1-4 = Relative mistletoe age
(1-oldest, 4-youngest)

Stage 1 -- Seedling Growth and Infection

Seedlings and saplings with live crown ratios $\geq$50 percent attain good height growth if not overtopped. Probability of infection by dwarf mistletoe, if present in overstory trees, increases dramatically after seedlings reach 3 feet tall or 10 years old, whichever occurs first.

Stage 2 -- Seedling Growth and Reinfection

Seedlings continue to grow at a rate directly proportional to live crown ratios and inversely proportional to the amount of competition. New mistletoe infections occur in the expanding crown from (a) surrounding infected overstory trees, if present, or (b) old infections in the lower crown.

If height growth is slow (low LCR), vertical spread of dwarf mistletoe will keep pace with or exceed tree height growth. If height growth is rapid (high LCR), trees will outpace the vertical movement of mistletoe but may be reinfected if infected overstory trees are present.

Stage 3 -- Cytospora Infection and Branch Mortality

Older dwarf mistletoe infections, primarily found in the lower crown, kill affected branches after an average of 11 years of parasitism. The fungus, *C. abietis*, infects branches through older mistletoe infections and may contribute to branch mortality, especially in stressed trees.

Stage 4 -- Tree Growth, Reinfection, and Branch Mortality

Reinfection by dwarf mistletoe, especially from surrounding infected trees continues in expanding crowns. More branches die as a result of (a) shading due to crown closure by surrounding trees, and (b) old dwarf mistletoe--*C. abietis* infections. Consequently, tree growth declines drastically as LCR falls below 40 percent and DMR exceeds 4.

Stage 5 -- Secondary Pests and Tree Mortality

Poorly growing trees are attacked by fir engravers, first in upper crowns, resulting in top mortality and then in mid and lower crowns, contributing to further tree decline. Root pathogens, primarily *A. mellea* and/or *F. annosus*, infect wounds (especially *F. annosus*), major roots, and root collars, and also contribute to tree decline, especially in weakened trees. Branch mortality continues until only recently formed adventitious branches remain. The combination of branch mortality, fir engraver attacks, and root diseases finally kills the tree.

Two main factors affect the time interval between Stage 1 and Stage 5: individual tree LCR and DMR, which are in turn affected by the level of competition, either from the overstory or from adjacent trees and by DMR of those surrounding trees. The faster a tree attains a low LCR and high DMR, the shorter the time interval between Stage 1 and Stage 5.

V. Management Recommendations

There are several ways to maintain good tree growth rates and minimize damage caused by white fir dwarf mistletoe and associated pests:

Seedlings

Remove overstory trees within 100 feet, especially if they are infected with mistletoe, before the understory is 3 feet tall or 10 years old, whichever occurs first to (a) prevent infection of regeneration, and (b) reduce shading and subsequent development of poor LCR.

Saplings and Poles

Thin densely stocked clumps as early as possible and favor other tree species or vigorous firs with LCR $\geq$50 percent and DMR <3; LCR being the more critical. If there are not enough trees meeting these criteria to maintain full stocking, consider stand replacement to avoid severe growth loss and early mortality. Rapidly growing firs also are less susceptible to Indian paint fungus infection and will heal more rapidly if wounded.

Sawtimber

In any decision to retain or harvest mistletoe-infected sawtimber stands, retain those trees with the highest average LCR and lowest average DMR i.e., the faster growing stands. Stand decline and mortality will increase dramatically as the proportion of trees within the stand with LCR <40 percent or DMR >4 increases. We estimate that grand fir sawtimber with LCR <40 percent or DMR >4 is highly susceptible to root disease and fir engraver attacks and probably will not survive for another 20 years. If a high proportion of such trees occur and stands are less than 100 years old, thin to retain other tree species or firs with LCR >60 percent and DMR <5. If there are not enough trees meeting these criteria to maintain adequate stocking or stands are too old to respond to thinning (over 100 years old), replacement should be considered to avoid severe mortality losses.

The following cutting priorities may be used as a guide when harvesting or thinning grand fir stands with dwarf mistletoe (Fig. 8).

	Individual trees or stands with a high proportion of trees with:
First Priority	- LCR <40% - LCR = 40-59% with DMR = 5 or 6
Second Priority	- LCR = 40-59% with DMR <5 - LCR $\geq$60% with DMR = 5 or 6
Third Priority	- LCR = 60-79% with DMR <5
Last Priority	- LCR $\geq$80% with DMR <5

Avoid developing recreation sites in mistletoe-infected grand fir stands. Such stands are short lived. Also, severely infected mature stands usually contain a high proportion of bole infections, which may become open cankers and a potential point for stem failure.

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Prepared by: Gregory M. Filip
GREGORY M. FILIP, Plant Pathologist — 5/20/82 Date

Reviewed by: James S. Hadfield
JAMES S. HADFIELD, Supervisory Pathologist — 5/25/82 Date

Approved by: Paul E. Buffam
PAUL E. BUFFAM, Director, EPM — 5/25/82 Date